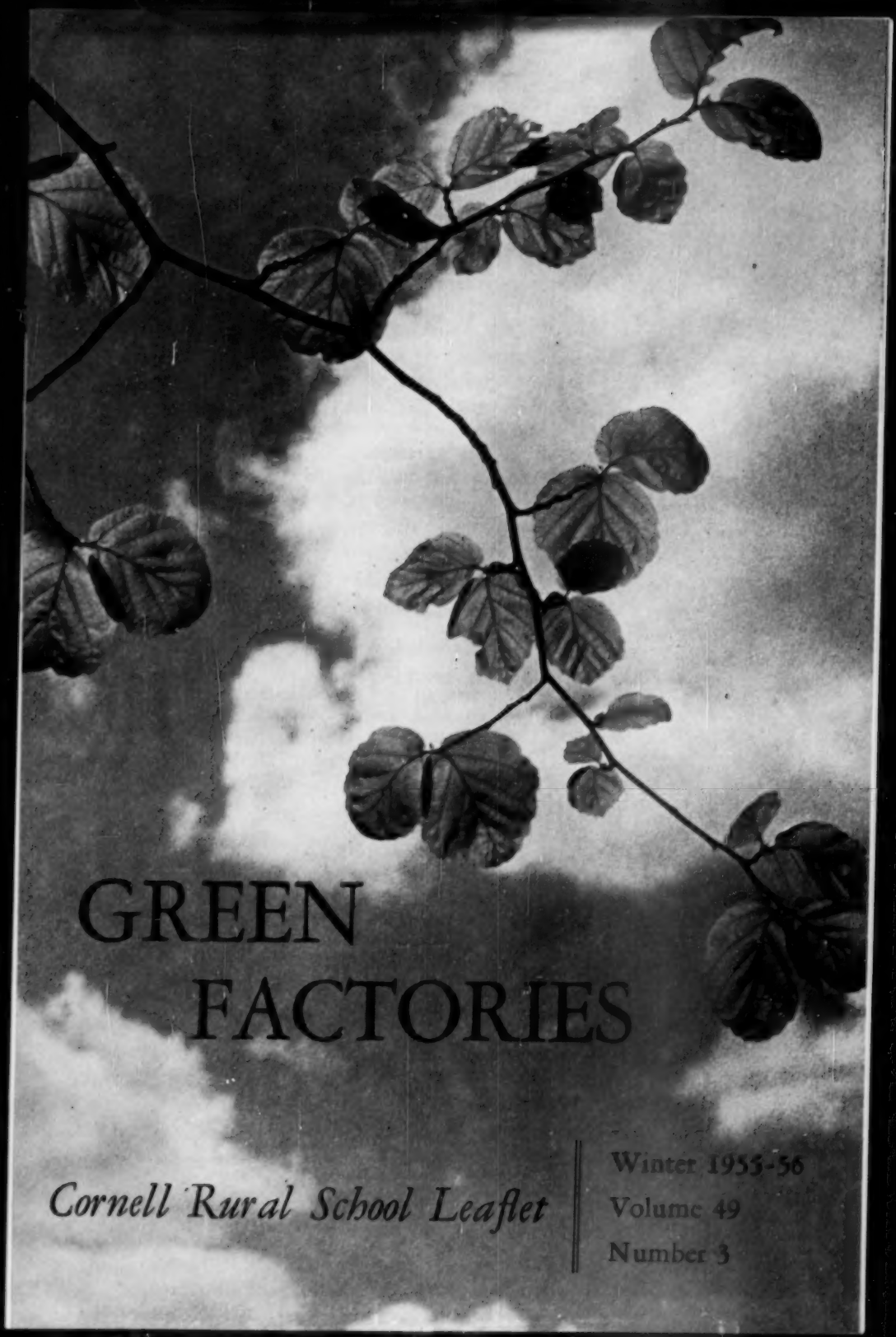


GREEN FACTORIES

Cornell Rural School Leaflet

Winter 1955-56
Volume 49
Number 3

CORNELL RURAL SCHOOL LEAFLET

PUBLISHED BY
THE NEW YORK STATE COLLEGE OF AGRICULTURE AT
CORNELL UNIVERSITY, ITHACA, NEW YORK
W. I. MYERS, DEAN OF THE COLLEGE

THE DEPARTMENT OF RURAL EDUCATION
ANDREW LEON WINSOR, HEAD OF THE DEPARTMENT

PREPARED AND SUPERVISED BY
EVA L. GORDON
ASSOCIATE PROFESSOR OF RURAL EDUCATION

EDITORS FOR THE COLLEGE
WILLIAM B. WARD
NELL B. LEONARD

Acknowledgment

The help of Professor Daniel G. Clark, of the Department of Botany, New York State College of Agriculture at Cornell University, in planning and preparing this Leaflet is gratefully acknowledged. Cover photograph (witch-hazel) and those on pages 3, 4, 9, 10, and 15 by R. B. Fischer. Drawings on pages 7, 9, 12, 13, 19, 24, and 25 by Doreen Perelli.

A publication of the
New York State College of Agriculture,
a unit of the State University of New York,
at Cornell University

Green Factories

By Eva L. Gordon

ALMOST any one of you can find a green factory at work if you look around. From early spring until the trees are bare and snow covers the ground, many of you may see more green factories than any other one thing whenever you are out-of-doors or even look out through a window. Probably you know that the green factories I mean are the green parts of plants. Can you see some today? Do you have any in your classroom?

Have you ever stopped to think how much you and every other animal depend upon these green factories? How many things have you used *today* that came directly or indirectly from green plants? You can easily discover for yourself what important living things green plants are when you find how few things you would have to eat, to wear, or to use in many other ways if there were no green plants in the world. Someone once wrote, "We live upon our earth because it is green." What do you think about that?

Living Things

Living things—plants and animals—are alike in many ways. Perhaps you will want to discover for yourself what some of these likenesses are. You will have the beginning of a list when you finish working with this Leaflet. Science books may help you, too.

Living Things Need Food

One way in which all living things are alike is this: they need food. Take yourself, for example. You know how necessary it is for you to have enough good food to keep you healthy and active and to help you grow. Day and night,

In one summer, this pigweed grew nearly 6 feet tall, with a 6-foot spread, using food made by its green factories

no matter what you are doing, your body is using food you have eaten. You do not need to eat all the time. But you would die if you did not eat at all.

Other animals are like you. They need food to enable them to live and to do all the things they do. Think of the different kinds of food eaten by animals you know! Think of the different ways animals get their food!

Plants are like you, too. Without food they could not live and grow. They need food to give them energy and to serve as building materials for their bodies. Like you and other animals, plants have their own ways to get the foods they need.

Other Needs of Living Things

You know that you need water to drink and air to breathe. Is this true of other animals? Do you know how your body uses the oxygen in the air you breathe?

You know that plants, too, need water. Do they also need air (oxygen)? Do they use oxygen much as your body does? What do your science books tell you about this?

The Food of Plants

Probably you have learned in your health or science studies that your body needs several kinds of food and certain minerals and vitamins, as well as water and oxygen. Not long ago I saw, in a fifth-grade room, charts that suggested foods you could choose to satisfy these needs. Perhaps some of you will want to learn more about this subject before you go on with this Leaflet. You can find information in many books and other helps. What do you know, or can you learn, about the three big classes of foods used by you and other animals: (1) **sugars and starches** (*carbohydrates* is one name for both); (2) **fats and**

oils; and (3) **proteins?** What about minerals and vitamins? water? oxygen? How do you and other animals get what you need? How much of your food comes from plants?

Carbohydrates, fats and oils, and proteins are essential foods for plants, too. Most plants—the green ones—can do something that neither you nor probably any animal you will ever see can do. All green plants are food factories. They can *make* the foods they need from materials they get from the air and the soil. Animals must have ready-made food—from plants or from animals that eat plants.

Can you see that green plants are the world's food makers—the most important factories in the world? All the energy-producing foods that you and other animals use come directly or indirectly from plants. Even some kinds of plants are dependent for food on those plants that contain the green substance called *chlorophyll.* Most bacteria, mushrooms and other fungi, and a few flowering plants, such as Indian pipe and beechdrops, are examples. Some of these plants take their food from living plants. Others take theirs from dead plants. You can learn more about them from your science books.

Some of you may discover that a very few kinds of plants, most of them bacteria, can make food for themselves from certain chemicals even though they lack chlorophyll. You can wait until you are older to learn more about that!

Green plants use various minerals and vitamins, too. They get their minerals from the soil, and they build their own vitamins. Do you?

As you read on in this Leaflet, you will learn that green plants do not *make* food all the time, any more than you eat all the time; but, day and night, while they are alive, they, like you, constantly *use* food—sometimes very little, sometimes more. Even dry, ripe seeds, not yet

The book in the background indicates the size of this Indian Pipe. At bottom right is an Indian Pipe of the preceding year

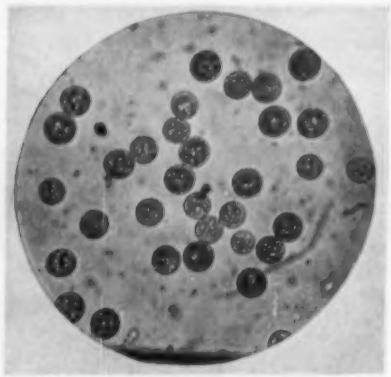
Photo by V. N. Rockcastle

planted, use some of the food stored in them as long as they remain alive.

When their green factories are at work, plants *make* and *use* food at the same time, although they usually make more than they use. Some is stored in roots, stems, seeds, fruits, or other parts of plants. You know that *you* use some of this stored food. Do the plants themselves?

Some Things to Do

Watch new carrot leaves grow from a carrot. First take off the wilted leaves. Then cut off about 2 inches from the big end of the carrot. Place this piece, large end up, in a shallow dish of water, with pebbles around it to hold it in place. Keep the carrot about half covered with water. What happens to the carrot as new leaves grow?



From photomicrograph by J. M. Kingsbury

These one-celled algae were found in an Ithaca mud-puddle. In the picture they are magnified hundreds of times

Grow new beet leaves from a beet in the same way. If you can give your beet lots of bright sunlight, the leaves may be red. Then you can follow the suggestion on page 11.

You may see that the carrot or beet shrinks. You may decide that it does so as the stored food is used to produce the new growth. As an experiment you might compare the growth of two carrots or two beets, one with plenty of stored food, the other with very little. Try a 2-inch piece and a half-inch piece of each vegetable. Choose vegetables of as nearly the same size as you can. Put them side by side in the sun. Keep them both supplied with water. Watch to see whether there is a difference in the number of new leaves, their size, or the length of time the new growth lives.

"Plant" another 2-inch piece and another half-inch piece of carrot or beet in water in another dish. Put them in a warm, *dark* place, such as under a cardboard carton. Keep them supplied with water. Compare their growth with that of the vegetables in light. They have *only* the stored food to use. The new leaves that grow in light may make some food for themselves.

Food Making by Green Plants

Around you are green plants of many kinds, from tiny algae too small to be seen with unaided eyes to towering trees. These plants, or parts of them, are green because they contain the green chemical called *chlorophyll.* We know that such plants make their own food—and ours, too. Chlorophyll is one reason they can do this.

Scientists have learned much about the raw materials green plants use, and the kinds of foods and other substances they make. These men have discovered much about how plants do these things; but even after long years of careful study, no one fully understands the marvel of food manufacture by green plants. No one, even in the best equipped laboratory, has been able to do in a test tube what a green plant can do in its green factories.

If you have studied how automobiles are made—or bread, or woolen blankets, or other things men make in factories—you know that their manufacture usually takes place in steps. Often many processes, sometimes in different factories, are necessary before raw materials become finished products. Sometimes the product of one step (flour, for example) is a raw material for a later step—making bread, or cake, or pie. Using what you know about man-made factories may help you to understand plant factories.

The first steps in food-making by plants take place in their green parts. Because these green factories work only when light shines on them, this important part of the process is called *photosynthesis,* which means *putting together* (*synthesis*) *with light.*

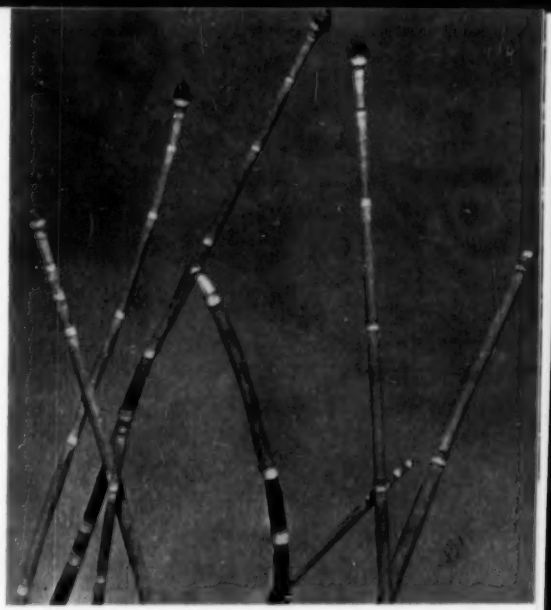
You can begin to learn about this important process in at least three ways that older students use: (1) you can do some exper-

This seaweed is an alga, too. Its stipe (stemlike part) may be 25 yards long, its blades 5 yards

ples and elms, have "one-piece" blades, and are called *simple leaves*. Others, such as the Virginia creeper shown on page 11, have blades made up of several leaflets, and are known as *compound leaves*. Can you find differences in the petioles, too? Are some long, some short, some straight, and others bent, or curved, or twisted?

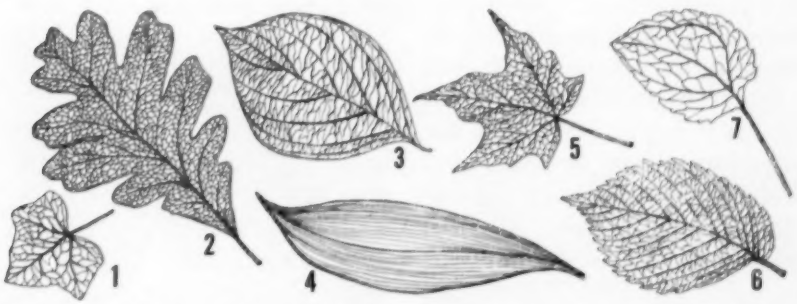
Look carefully at the veins of leaves you find. Where are the smallest veins? Where are the smallest parts of the large veins? Do you see that the veins unite with each other? Do you see that one or more of the large veins enters the petiole at the base of the blade? You will be glad you noticed all these things as you go further into the study of plants and their food.

Now, look at a whole plant—at home or in your schoolroom.



The green factories of this Scouring Rush are in its stems

Choose one that has stood for several days in the same position facing a window. Does the light shine on the greater part of most of the leaves? Are most of the leaves broadside to the light? Notice how the leaves are arranged on the stems. Look at



These leaves differ in form and in vein pattern: 1, English Ivy; 2, White Oak; 3, Flowering Dogwood; 4, Lily-of-the-Valley; 5, Sugar Maple; 6, American Elm; 7, Black-eyed Susan

iments; (2) you can make some observations; and (3) you can read. If you do all these, you surely will understand better how wonderful green plants are.

Some Things to Do

As you read you will meet many new words. Take time to think what they mean, and to learn to pronounce them. Then you will find it easy to use them when you wish. Knowing them will help you as you read.

You will need some plants to observe, and to use in your experiments. Have you some that are already growing? Can you get some? You may want to raise some new plants, from seeds or in other ways. Beans are a good choice to grow from seeds. They are easy to raise and they grow rapidly. You can find other useful suggestions in your science books or in your library.

About four-fifths of all kinds of plants are green plants. By studying their likenesses and differences, scientists have divided them into large groups. The group you probably know best is composed of flowering plants: apples, elms, zinnias, and many more. Another familiar group includes the cone-bearers —pines, spruces, cedars, and others. You surely would add ferns and mosses to the list. Can you think of, or find, others? Don't forget the algae (pronounced *al*-jee, singular, *al*-ga, with *g* as in *go*.) Can you find specimens or pictures to illustrate each of the groups you list? Even if you are using this Leaflet in midwinter, you may be able to find some specimens.

Look for specimens or pictures of plants that are never green, and that cannot make their own food.

The Green Factories

Leaves are the chief food factories of most green plants, but any plant part that contains chlorophyll may manufacture food if it is in light. Can you find green parts other than leaves on plants you can examine? Many cacti have only small leaves, or keep their leaves only a short time. What parts of them are often green?

Think of the kinds of leafy plants you know. Their leaves differ, do they not? Even those on a single plant, such as a maple tree, are not exactly alike. But most leaves have at least these two parts: (1) a broad, thin *blade*, marked into small divisions by *veins;* and (2) a leaf-stalk or *petiole*. Examine leaves that you can find, even though it is winter. Notice how their blades differ. Some, such as ma-

night.) Place the leaf on a piece of thick soft cloth, or on several thicknesses of soft cloth. Find a brush with close, moderately fine bristles, such as the fingernail brush illustrated on page 10. Hold the brush by the end of its handle, and bounce its other end firmly but gently against the leaf. Patiently tap again and again, until the bristles have picked out the fleshy part of the leaf, leaving the veins unbroken. When you have completely skeletonized your leaf, dry it between pieces of newspaper, under a heavy book or some other weight. Then mount it between pieces of glass or cellophane. A skeletonized leaf will help you to see how leaf veins branch and join each other. It may help you to understand better what you read on page 21.

If you can get two or three leaves of beet plant (*Iresine*) or of red *Coleus*, you might try this! (I tried red leaves of garden beets, too.) Put your leaves in a pan (a light colored enamel pan is best), and cover them with water. Boil them for a few minutes. Ten minutes was long enough for the beet plant, the *Coleus*, and the blade of the garden beet leaf, but not for the garden beet leafstalk. What color dissolves into the water? Pour off the water or lift out the leaves. What color are they? Does chlorophyll dissolve in water?

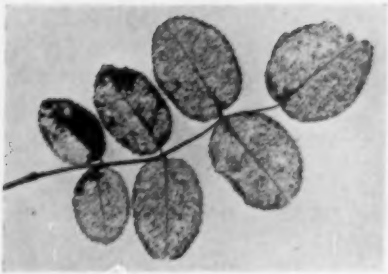
The Workrooms—Plant Cells

Only after microscopes had been invented did people discover something you probably have read in science books: that all living things—plants and animals—are made up of tiny bits of living material called *cells*. You may want to read more about this, because I shall mention only a few of the facts we know about cells.

A living thing may be *one-celled* or *many-celled*. When there are enough of them, certain one-celled green plants may make the water in your aquarium appear green. You may find another kind on the moist, shaded side of a tree trunk or an old fence. Millions, close together, look somewhat like a

Most of the compound leaves of this Virginia Creeper are broadside to the light

Photo by W. C. Baker



A skeletonized rose leaf

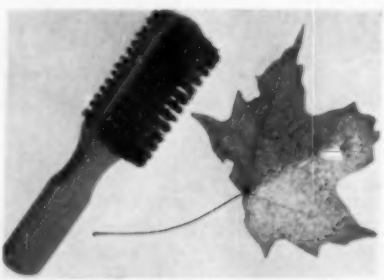
up-and-down (vertical) stems, and at those that grow horizontally or slanted. Can you see how the light that shone on the leaves influenced the position the blades took and the way the petioles grew—some longer than others, and some straight, or curved, or bent, or twisted? When you have finished your observations, turn your plant so that the opposite side faces the window. Are the leaves now well placed to get the light they need? What happens after a time? In some plants you can see changes in a few sunny hours. You may have to watch others for several days.

You can have an interesting trip in the spring to study the different ways in which leaves are arranged in light. Leaves of plants that get light from all sides may be arranged quite differently from those on other plants that get most of their light from one side. Do you remember how dandelion leaves are arranged? leaves of vines on the wall of a building? Look for leaves that change their positions through the day as the light changes.

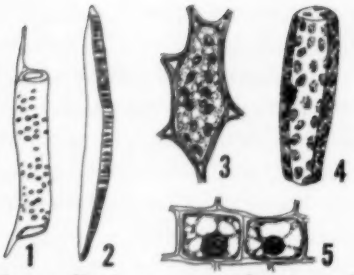
Do you know that green plants do not always look green? Beet plant (*Iresine* and *Bloodleaf* are other names) and some varieties of *Coleus*, for example, have red leaves and stems. Some beech and some Norway maple trees have coppery leaves. Purple cabbage certainly does not look like a green plant. But such plants have chlorophyll, too, hidden by the colors you see.

Some Things to Do

Often you find skeleton leaves, such as the one pictured above, on the ground under trees or shrubs. Insects, fungi, or moisture make them. You can do it, too. Choose a leaf with rather tough veins. (I used a fallen maple leaf, soaked in water over



The brush shown was used to skeletonize the lower part of the sugar-maple leaf



Plant cells: 1, water-conducting cell, and 2, food-conducting cell, both from apple; 3, cell from moss leaf; 4, cell from upper part of leaf; 5, onion-root cells. All greatly magnified

(1 and 2 are adapted by permission from "Introduction to Plant Physiology," by Curtis and Clark, 1950, and from "Introduction to Plant Anatomy," by Eames and MacDaniels, 1947. McGraw-Hill Book Company, Inc.)

cells in a many-celled plant make enough for themselves and for the other cells as well.

Green plant cells are the food-making cells—the workrooms for photosynthesis. They contain the "machinery" for manufacturing certain plant foods from materials in water and air, using sunlight (or other light) for energy.

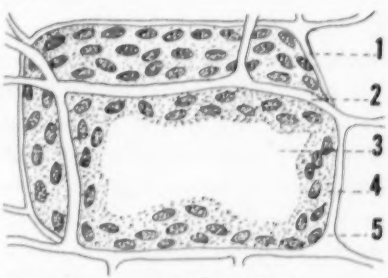
Perhaps someone can give you a microscope view of green plant cells, the green factory workrooms. Perhaps you can see other types of cells, too. Anyone who knows how to use a microscope can find what plant parts to use and how to prepare them. I have seen good suggestions in some elementary-school science books. The picture on page 25 may help you know what to look for.

Something to Do

Cotton often is more than 90 per cent cellulose. Cellulose is an important part of many useful natural materials, wood, for example. It is used in the manufacture of many products, paper, for one. What can you learn about this?

The Machinery

If the picture on page 25 were correctly colored, all the pinhead-sized dots in it would be leaf green. You can see that these dots are just inside the walls of some (but not all) of the cells in the drawing. They are called *chloroplasts*, which means *green bodies*, and are bits of the living protoplasm of the cells. They give leaves and other green parts of plants their green color.



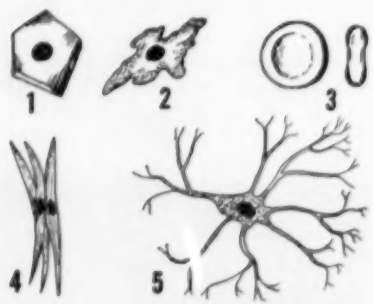
Greatly magnified cell from an Elodea leaf: 1 and 2, cell wall; 3, vacuole filled with cell sap; 4, protoplasm; 5, chloroplast

splash of green paint, but you could not see one alone.

Most of the flowering plants you see around you have many millions of cells. A botanist once estimated that 90 years would be needed to take apart just one full-grown apple leaf, removing one cell each minute. A 3-inch apple may contain as many as 500,000,000 cells. Think how many cells a whole apple tree might have—in leaves, branches, trunk, roots, flowers, and fruits!

Most plant cells are too small to be seen except through a microscope, though some are bigger than others. Can you imagine any things so small that 40 of them would just cover one of the periods on this page? Yet some plant cells are even smaller.

Cells differ in form, as you can see from the drawings on pages 12 and 13. You can see from the pictures that cells have height and width. You must remember that they have thickness, too. Can you see that some of the drawings show that? Have you learned from these pictures that different forms of cells do different things?



Animal cells: 1, from lining of cheek; 2, bone cell; 3, red blood cells; 4, smooth muscle cells; 5, brain cell. All greatly magnified

In plant cells, the living material, called *protoplasm,* usually is enclosed within a firm *cell wall,* much like a package in a box. Often this cell wall is colorless and transparent. Plant cell walls are built up by the living protoplasm of the plant cells, but the walls themselves are not alive. They are composed of various materials, of which one is a substance called *cellulose.* Other substances besides the jelly-like protoplasm may be inside the cell wall, such as watery *cell sap,* and color-producers—*pigments,* we call them—that cause green and other colors. What colors have you seen in plants?

A one-celled green plant can carry on all its own life activities. But, in many-celled green plants different forms of living, growing cells carry on certain of their own life activities, and, besides, do special kinds of "work" that help to keep the whole plant alive and growing. Not all cells can make food by photosynthesis, but some of the

leaves and the green leaf blades of celery from the grocery store. Pour over the leaves enough alcohol to cover them generously. On a geranium leaf about 2½ inches wide I put 4 tablespoonfuls of alcohol. Cover your container. Set it where it will not get direct sunlight. After about 24 hours, pour the alcohol into a small clear glass bottle. What has happened to the color of the leaf? Hold the bottle up to the light and look at the alcohol solution. It is colored green, isn't it? Chlorophyll from the leaf cells has been dissolved by the alcohol. Some yellow pigments have been dissolved, too, but the leaf green hides the yellow color, just as it did in the living leaf.

Try the same experiment, using green leaves that have been dipped in boiling water for about a minute. Does their chlorophyll dissolve faster? (The boiling water killed the leaf cells, and softened the cell walls.) You probably will want to extract chlorophyll from leaves in this way when you do some of the experiments mentioned later in this Leaflet (page 30).

The Energy—Light

You know very well that the earth receives light from the sun. You can see the sun's light and feel the warmth produced by it. Light and heat are forms of energy—they have the power, or ability, to do things. You probably have learned about this in past science studies.

The leaves of this creeping Partridge-berry receive light only from above

The light energy of sunlight produces many chemical changes. You have experienced some, I think. In the hot, bright summer sun, your skin tanned, or more freckles appeared on your nose, or your hair changed to a lighter shade—all the result of chemical changes in substances in your skin and hair. Much the same thing happens when curtains in a sunny room fade or their colors change.

You make use of chemical changes produced by light when you take or print a photograph. In fact, the word, *photograph*, comes from two Greek words

Chloroplasts get their green color from the wonderful chemical substance called *chlorophyll*, which means *leaf green*. Some plant cells produce this chemical, but no one knows exactly how they do it. Scientists do know that proper light and proper temperatures are necessary; and, of course, the necessary materials. Perhaps you have found pale, yellowish grass under a board, where there was too little light for chlorophyll to be formed. Sometimes if you leave such grass uncovered so that light can reach it, it will become green. Usually chlorophyll is not formed in plant parts that light does not reach, such as the wood of a tree, or the flesh of an apple, or the underground parts of plants. But you may have seen green places on potatoes, where they have been exposed to light.

Why is this chlorophyll so important? Because without it there would be no photosynthesis, and therefore no food for all but a very few plants, or for animals. No one knows just how chlorophyll works, but in some way it is able to absorb the energy of light and use it to cause certain chemical changes inside plants. These chemical changes transform water, and carbon dioxide from the air, into sugar. In plant cells sugar can be changed to starch or starch to sugar. From these carbohydrates (and sometimes added materials) the cells can build fats and proteins, and so make for themselves the "big three" groups of necessary foods.

Chlorophyll is essential "machinery" for the first steps in food making by plants, and sugars are the first foods produced. Men can take chlorophyll from leaves (extract it), and use it to color toothpaste, gum, medicines, soaps, and other things. But they cannot use it, as plants do, to make the foods they need.

Something to Do

Probably you have accidentally extracted chlorophyll from grass or other plants, and called it "grass stain." You could not do that easily now, in winter. But you can rub a fresh green leaf on white paper or cloth and make a chlorophyll stain. Or, you can extract chlorophyll from green leaves with alcohol—ordinary rubbing alcohol will do.

Put one or two small fresh leaves into a glass or china dish that you can cover tightly (to prevent evaporation of the alcohol). A wide-mouthed glass jar with a lid is a good choice. Thin-bladed leaves are best, but I got good results from both geranium

The Raw Materials

Several times in this Leaflet I have mentioned that green plants use "materials they get from the air and the soil" to make the foods they produce. In photosynthesis, they use just two materials. One is water, which land plants get from the soil. The other is an invisible gas from the air, called *carbon dioxide*. From these two substances, which are *not* foods, they make sugar which *is* food.

Water is a familiar substance to all of you. You use it every day. Probably you have studied water and experimented with it. Perhaps you even know it as H_2O, a chemical compound of 2 atoms of hydrogen and 1 atom of oxygen. (If you need to know more about this, your science books can tell you much.)

Plants use water in many ways. They need it to keep alive and to grow. Plant cells are largely water, and much of the weight of a living plant is due to the water in it. (Perhaps you know that your body is about three-fifths water.) Of all the water taken in through the roots of plants, only a small part is used directly in photosynthesis.

You must think of water as H_2O, when you study its part in photosynthesis. You have read or heard about hydrogen, haven't you? And you know that oxygen, one of the gases in air, is necessary to keep you alive. You breathe it into your body with every breath. Plants use it in their bodies, too, much as you do. In nature, both hydrogen and oxygen are gases, but 2 atoms of hydrogen and 1 atom of oxygen, put together chemically, become water. Energy is necessary to change water to hydrogen and oxygen.

Carbon dioxide is a chemical compound, too, known as CO_2. Like oxygen, it is one of the invisible gases in air. It is the gas that bubbles out of soda pop and that makes an ice cream soda foamy. People use it in some kinds of fire extinguishers. We and other animals breathe out carbon dioxide. Plant cells, too, give it off as they use their food. Green cells take it in when they are making food.

A molecule of carbon dioxide (CO_2) has 1 atom of carbon and 2 atoms of oxygen. (A *molecule* is the smallest possible particle of a substance.) You have seen carbon, though perhaps you did not know it. Soot is carbon. So are diamonds and black pencil leads. Charcoal and coal are mostly carbon.

If you have been thinking, you know now that water and car-

that mean *light* and *to write*.

For living things, probably the most important chemical changes brought about in part by light are chlorophyll building and photosynthesis, *putting together with light*. Sunlight usually supplies the light energy, although light from other sources will serve. Wherever sunlight reaches green plant cells—on land or in water—photosynthesis may work its magic, if proper conditions are present.

You know that our small earth receives only a little of the huge sun's energy—it is given off into space in all directions. Only part of what the earth receives reaches green plants. And green plants can absorb and use only part of what comes to them. But that little bit is enough to start food-making processes that provide food for almost every living thing on earth. Plants and animals get energy from their foods, really the stored-up energy of sunlight. You might say that their food is partly captured sunlight, put there by plants.

Some Things to Do

Put a piece of colored paper in a sunny place. Cover part of it with a book or something through which light cannot shine. Lift your covering every hour or so. How long is it before the chemical change you call *fading* begins to show?

A blueprint is a good example of a chemical change produced by light. Perhaps some of you would like to make prints of a green factory or two. You can find directions in books, or you may write to the Nature Study Office, Stone Hall, Cornell University, Ithaca, New York, for mimeographed instructions.

The Working Hours

The "machines" of most green factories are run by sunlight. So their working hours are all the hours of sunlight. At night photosynthesis stops—no more sugar is made. On cloudy days, when they get less light, the green factories work more slowly.

Of course, green factories do not always work in "all the hours of sunlight." Sometimes temperatures are too low; or some other conditions interfere.

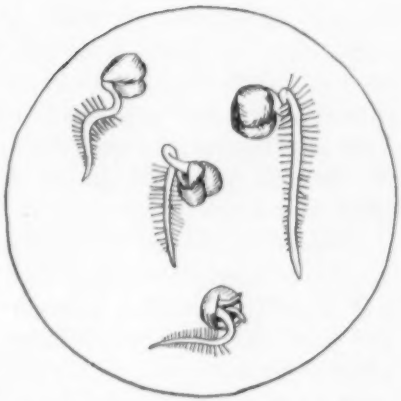
Have you ever seen plants grown in artificial light? Where? Was *only* artificial light used; or did the plants have natural light part of the time? What kind of light was used? Why was artificial light used? Plants have been grown wholly in artificial light, but the process is too expensive to be generally used.

flowers or cones, each of which has some special part—*function* is a better word—in the life of the whole plant. Most such plants have their tops in the air and their roots in the soil. Large or small, they get water from the soil through their roots.

Root Hairs

The roots of various kinds of plants differ, but most of them get water from the soil in much the same way. Roots branch as they grow—branch again and again into finer and finer roots. Near the growing tips of the younger roots of most plants are fragile, thin-walled *root hairs*, parts of cells that extend out between particles of soil. Most root hairs are almost too small to be seen with the naked eye. Hundreds may grow on an inch of root. They grow rapidly, but they do not live long. The older root hairs die, and new ones continually grow near the tip of the root as it pushes farther and farther into the soil. This is important, because root hairs absorb most of the water that is taken into these land plants. The way the root hairs grow brings them constantly into contact with new supplies of water.

Water enters root hairs through their thin walls by a process called *diffusion*. You



Root hairs on young radish plants

Redrawn from "Plant Factories," by permission of Row, Peterson Company

have experienced diffusion of a gas through air when you have smelled the fragrance of someone's perfume. You can see diffusion through water if you gently drop a little food coloring into clear water. Do not disturb the water nor stir it. The slow spread of the dye until the water is evenly colored is diffusion. How diffusion operates is something you can learn in later science studies. It is an important and interesting principle of physics.

You can see root hairs by sprouting bean or radish seeds. Line a small glass jar with a piece of colored blotter. Put enough water in the jar to moisten the blotter. Place your seeds between the moist (not wet) blotter and the inside of

bon dioxide contain only 3 chemical elements (substances made up of only one kind of atom.) They are C, carbon; H, hydrogen; and O, oxygen. Light energy, with chlorophyll, makes them into sugars.

Some Things to Do

Put one-half teaspoonful of baking soda into a small glass jar or bottle. Add vinegar slowly. The gas that bubbles out is carbon dioxide (CO_2).

Put a teaspoonful of white sugar on the metal lid of a jar or can. Heat the sugar slowly for several minutes. Watch it closely. The white sugar turns first to a brown sirup. You can see a misty "cloud," like the cloud of tiny droplets of water near the spout of a teakettle in which water is boiling. After a short time the sirup changes to a black, bubbly material. Heat energy has taken the sugar apart and driven off water, leaving carbon, although perhaps not pure carbon. If you take your can-lid away from the heat as soon as you can no longer see the cloud of water droplets rising from it, you can cool the carbon and taste it. Does it taste like sugar? If, instead, you leave the can-lid exposed to enough more heat, the carbon will burn, and you will have at most only a tiny bit of ash.

The Supply Department

You remember, don't you, that in photosynthesis, food-making plant cells use two raw materials: water and carbon dioxide? Most kinds of plants get water from the soil, and carbon dioxide from the air. Let's learn a little more about how these raw materials reach the plant cells that use them. The green factories of a maple tree, for example, are high above the ground. How does water get to them from the soil? Air is all around maple leaves, and there is carbon dioxide in the air. But how does it get to the green cells? How do the green cells of an aquarium plant or a pond plant that grows under water get their supply of carbon dioxide? Don't plants that grow in water get their water supply from the water around them? You probably will have other questions. You will surely find the answers to some in the next few pages.

The Water Supply

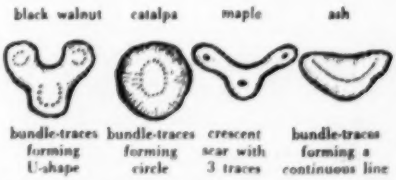
Probably most of the plants you know have roots, stems, leaves, and other parts, such as

(That helps to make sure that the conducting tubes are not blocked with air.) Quickly place the cut stem in colored water. Put the flower in bright light for several hours. You can use an electric light if there is no sunlight. Does what happens show that water travels up through stems?

Leafy branches from a geranium can be used, too. Get two branches, if you can. Cut the lower end of each with a sharp knife, and put them immediately into water colored bright red. Set them in bright light for several hours. Then cut off the lower inch or two of the stem of one. Can you see where the red liquid traveled? Can you see color at both ends of the piece you cut off? If you can, cut off more small pieces until you learn how far the liquid rose in the stem. Put the remaining part of the branch back into the colored water, for more observation later. Leave the other geranium branch in the colored water until you can see red color in the leaves. Which leaves show the most color? Look at the tip of the branch. Is it colored? Cut the stem lengthwise past the lowest leaves. Can you trace the path of the water up through the stem, and out into a leaf? You may need to cut away a bit of the stem, carefully, to see this. Don't throw your geranium branches away—you can use them again later.

Into Leaves. From stems, water-conducting tubes branch off into leaf petioles, and go on into the leaf blades. There, they form part of the veins. If you skeletonized a leaf as suggested on page 10, you have something to help you imagine how very small these bundles of water-conducting tubes become. Even the finest of leaf veins has three parts —tubes that bring in water, tubes that take out food, and a sheath that encloses them both.

Now, look at that geranium leaf that showed red color. Hold it up to the light, and notice the branching of the veins. A magnifying glass will help you see the finer veins. Of course, you cannot see it, but this is true: every cell in that leaf is near enough to one of those tiny veins to get a supply of water. What



From Morton Arboretum, Lisle, Illinois

The dots in these leaf-scars show where food- and water-conducting tubes entered leaf petioles

the jar. Cover the jar with a metal can. (Roots grow better in the dark.) When the seeds have sprouted, look at their roots with a magnifying glass. Near the tip, you probably will see a place that looks like a tiny bottle brush. The "brush" is made up of root hairs. Water and dissolved substances pass through the thin walls of the root hairs into the roots.

Plant "Pipelines"

From the root hairs water moves into the smaller roots, then into the larger ones. It travels on into the stem, and then to every branch and leaf, flower or fruit—everywhere in the plant that living cells are at work. It moves by way of very fine tubes, like tiny soda straws, that begin in the roots and end in the outermost parts of the plant. These water-conducting tubes are formed from cells that were once alive, but are no longer living cells.

Through Roots. The water-conducting tubes are in the center of roots. To see this, get, if you can, a young carrot with fresh-looking leaves. (A carrot is a root, you know.) Keep the leaves on, but cut off the tip of the root. Put the carrot into cool water for an hour to freshen. Then put it into a jar of cool water strongly colored with green or red ink or food coloring—the kind your mother uses to color cake-frosting and other things. Set the jar in bright light for several hours. Then remove the carrot and cut it lengthwise through the middle. Did the colored liquid travel upward through the central core of the root? Gently separate the core from the outer part of the carrot. Can you find where bundles of water-carrying tubes from the small roots join those in the core? Did some of these show color, too? Try the same thing with a carrot without leaves and put one with leaves and one without leaves in the dark to see whether you can detect any differences in the way the liquid travels. Does ink work better than food coloring?

Through Stems. The water-conducting tubes of roots connect with those in stems. Where the bundles of water-conducting tubes are in stems depends upon the kind of stem, or rather upon the kind of plant. You probably have studied how trees grow, and know that in trees, such as maple trees, they form the sapwood. Here are some ways to observe water passing up stems. Hold a white carnation with the end of its stem under water, and cut off a small piece of the stem.

ways. One-celled algae and some other plants take water directly from their surroundings into the cells where it is used. Many of these plants live in water or in wet places. Mosses, and some other plants without true conducting systems, take in water through special plant parts, and the water passes from living cell to living cell, so that each is supplied. Plants, like animals, have different ways of doing the same thing.

Water Has Many Uses

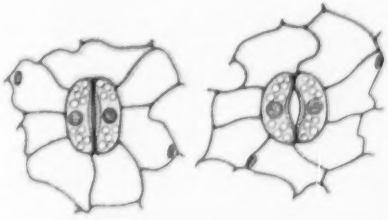
Water constantly enters and leaves plants. It passes in and out through the walls of plant cells. Many plant cells are chiefly water, and water plays a large and necessary part in cell activities. Water is essential for the absorption of needed materials by the cells and for the movement of dissolved substances—foods, minerals, and gases—from one plant part to another. Only a small part of the water that green plants take in is used for photosynthesis.

Carbon Dioxide for Photosynthesis

Ordinarily, only a very small part of air is carbon dioxide. Green plants use some of it whenever they carry on photosynthesis. But animals, automobiles, fires, and other agencies, even plants themselves, constantly replace the supply in the air. Perhaps you know, or can find out, how.

Just one leaf, such as a red oak leaf, may have thousands of tiny openings, called *stomates*, through which carbon dioxide can enter. In red oak leaves, these openings are only on the underside, as they are in many other kinds of plants. But red clover leaves, bean leaves, and some others have them on both surfaces. In water lily leaves, they usually are on the upper side only. And the leaves of some plants, such as the *Elodea* illustrated on page 27, have no stomates at all. Flowers, fruits, young stems—any plant part except the root—may have stomates, too.

Stomates, in leaves for example, are openings in a thin layer



The greatly magnified stomate at the left is closed; that at the right, open

is true in leaves is true, also, of all parts of plants where there are living, growing, working cells.

You can have fun watching the rise of colored water in a celery leaf, too. A stalk of celery, the part you usually eat, is really a leaf petiole (page 8), not a plant stem. If you choose a white stalk with white "leaves," the path of the colored water through it will be easy to follow. Cut off the bottom half inch or so, and put the stalk in cold water for about an hour, to freshen it. Then put it in colored water, and set it in bright light. After it has stood for about an hour, cut the stalk crosswise. How many colored spots show where water has gone up the stalk? Can you pull out from a lengthwise piece of the stalk one of the parts (bundles of tubes) that carry water upward? It is the "string" of the celery, isn't it? Can you see in the leaf blade how the veins branch again and again, into smaller and smaller branches?

Try other roots, stems, and leaves. Try a twig from a bush or a tree. I experimented with a white anemone with a 15-inch stem. Red color showed in the flower in about two hours, but I could not see it in the leaves until later.

Conducting Systems

Plants such as radishes, carrots, geraniums, water lilies, maple trees, and many others have true roots, stems, and leaves. Most such plants grow in soil, and get their water supply from it through their roots. Water lilies, and some others, even some that grow entirely under water, get part of their supply through their roots which grow in soil and part from the water around them.

The paths through which water is distributed to all parts of these plants is called the *water-conducting system*. Plants of all sizes have such systems, from the biggest trees to plants only a few inches in height. You have learned something of how conducting systems operate if you have read pages 18 to 22 and done some of the things suggested. I hope that some of you will want to learn more.

Plants Without "Pipelines"

Many kinds of green plants lack true roots, stems, and leaves. You can easily understand that one-celled plants are examples, but you may be surprised to learn that mosses are, too. Such plants have no true water-conducting systems. Their cells get their water supply in various

called the *epidermis*, that covers the whole outer surface. Usually the epidermis is only one cell thick. The cells of which it is formed are flat, box-like, irregularly shaped, and, for the most part, colorless. Scattered among the colorless cells are pairs of bean-shaped cells, called *guard cells*. Guard cells are the only cells in the epidermis that contain chlorophyll. Between each two guard cells is a stomate. You can see two pairs of guard cells, each with a stomate, in the picture on page 23. By swelling or shrinking as water and other materials move into or out of them, the two guard cells open or close the stomate between them. Even when it is fully open, each stomate is much smaller than the tiniest prick you could make with the finest needle. You could cover hundreds of them with the head of a common pin.

The tiny circle indicated by the arrow and the drawing on page 25 show the same part of the leaf pictured

Redrawn from "Plant Factories," by permission of Row, Peterson Company

Carbon dioxide, like other gases in the air, can move into the interior of a leaf through these tiny stomates when they are open. It moves by the same process, *diffusion*, that causes water from the soil to enter root hairs.

The picture on page 25 will help you to understand the inside of a leaf. Between the upper and the lower epidermis are soft, thin-walled cells that contain chlorophyll. They lie among the branching veins about which you read on pages 9 and 21. In most leaves, close to the upper epidermis, are sausage-shaped cells, placed close together. Below them are ball-shaped cells with larger air spaces between them. Carbon dioxide enters air spaces through the stomates, and can move freely through air spaces between the cells. It can reach every cell. It can pass through thin, wet cell walls. And, inside the chlorophyll-containing cells, it can be used in the making of sugar by photosynthesis.

You know that photosynthesis takes place only in light. The stomates usually open in light

and close in darkness, as the guard cells become swollen in light and shrink in darkness. As long as photosynthesis goes on, carbon dioxide is constantly used, and it usually continues to move into the leaf.

Some plants get carbon dioxide in other ways than through stomates. *Elodea* (page 27) and some other leafy underwater plants absorb carbon dioxide that is dissolved in the water. They, and some other plants, take it in through their cell walls.

Other Supplies

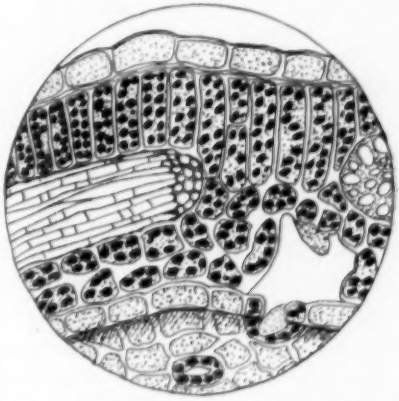
Only two raw materials are needed for photosynthesis: water and carbon dioxide. But green plants use supplies of several other chemical substances in other ways.

Mineral Elements

Good soil may contain all the mineral elements needed by green plants. But plant growers usually use fertilizers to add to the natural supply. If you know what chemicals are commonly provided by fertilizers, you have a good start for a list of mineral elements green plants need. Nitrogen is important, and about a dozen others are known to be necessary in smaller quantities.

In many familiar plants, these substances dissolved in water move by diffusion into plant roots. They travel in water to all parts of plants, probably chiefly through the water-conducting system described on pages 18 to 22. They enter some other plants through their cell walls.

You will learn in the next few pages that some of these mineral elements are used in plant cells to form proteins, a most important group of foods for plants as well as for animals. Certain ones are necessary to form chlorophyll and other substances, and to build protoplasm. Some are needed for proper growth and to produce new plants. Only



The cells have been drawn hundreds of times larger than they are. The darkest dots are chloroplasts; the ends of veins are shown at right and at left; the stomate at the bottom is on the underside of the leaf

Redrawn from "Plant Factories," by permission of Row, Peterson Company

small quantities of these minerals are needed, but they have many uses.

Oxygen

Plants need oxygen just as you do. You get most of your supply by breathing air into your lungs. Oxygen is taken into your blood and through it to all the living cells in your body. There it is used to change your food (also carried to your cells in your blood) (1) into energy to keep you alive, active, and growing, and (2) into building materials for your body.

Plants do not breathe as you do, of course. Oxygen enters plants in several ways: (1) from the air, through stomates or through cell walls; (2) through roots, from air held in the soil; (3) from water used as a raw material in photosynthesis; and, (4) through cell walls (especially in water plants) from air dissolved in water. Plants use oxygen much as you do—in their living cells, to change their food (1) into energy for life and growth, and (2) into building materials for their bodies. But in plants, water makes it possible for oxygen and food, as well as minerals to reach every cell and to move from cell to cell.

The Products of Photosynthesis

At least five times so far in this Leaflet you could have read that the plant food produced by photosynthesis is *sugar*. Do you remember reading this fact? On what pages can you find it?

Sugar is composed of three chemical elements: carbon, hydrogen, and oxygen (pages 17 and 18). A chemist would say that the type of sugar produced by photosynthesis is a *simple sugar*, with the *chemical formula* $C_6H_{12}O_6$. That is, each molecule is made up of 6 atoms of carbon, 12 atoms of hydrogen, and 6 atoms of oxygen. Some of you didn't know that there were different types of sugar, did you? All of them are made up of carbon, hydrogen, and oxygen, but in the different types the numbers of atoms of these materials vary, and they are put together differently. You probably are most familiar with cane sugar, which you use in such forms as granulated sugar, brown sugar, and confectioner's sugar. Its formula is $C_{12}H_{22}O_{11}$. Plant cells can make it from simple sugars. It is formed in the leaves of many plants.

Oxygen is another important product of photosynthesis. It is given off as sugar molecules are

formed in the food-making cells. Scientists have discovered that the sugar is formed from the carbon and oxygen of carbon dioxide and the hydrogen of water. The oxygen molecules (O_2) are formed from the oxygen of the water. Perhaps you remember reading on page 26 that part of the oxygen used by plant cells came in as a chemical part of water used in photosynthesis. Some of this oxygen usually is used in the cells where it was freed or in other cells. But during the day when photosynthesis is going on rapidly, some oxygen moves out of the cells, through the spaces between the cells, and out through the stomates—of leaves that have stomates. If you have an aquarium in your room, you may have seen tiny bubbles of oxygen gas rising from some of the plants when the sun was shining on the aquarium and photosynthesis was going on. *Elodea* (at right) is especially likely to show this. Oxygen that passes out of green plants helps to maintain a steady supply of this gas in the air. You know that living things constantly use oxygen.

How much sugar and oxygen are produced in a given time depends on many conditions. Temperature makes a difference. So do the kind and the amount of light and the supplies of carbon dioxide and water. Conditions within the cells may affect their working, too. Just one unfavorable condition may slow the manufacturing process and limit the quantity of sugar and oxygen produced.

Someone has estimated that green leaves, on the average, produce in a summer enough sugar to cover each leaf with a layer one millimeter thick. Do your rulers show how thick that is? Yet, the green factories of the world produce all the food used by practically every living thing.

At right, a sprig of Elodea; at left, bubbles rising from Elodea during photosynthesis (from Atkinson, "First Studies of Plant Life")

for other types of food. Without even one added material, simple sugars can be "made over" in plant cells into other types of sugar or into starch—carbohydrates, you remember. Fats and oils, too, are "made-over" from sugar, by living cells. Molecules of these substances have different numbers of carbon, hydrogen, and oxygen atoms, or the atoms are arranged differently—or, perhaps, both. Scientists know much of how these changes are brought about, and how and for what the different foods are used. You probably will learn more about these subjects later. But, isn't it amazing that from the same three chemical elements, living plant cells can produce three substances so different from each other: sugar, that tastes sweet and easily dissolves in water; starch that is practically tasteless and is not soluble in water; and fats that make grease spots?

To make proteins, more materials must be added to sugar. Protein always contains nitrogen (page 25) and often sulfur or phosphorus or both. Proteins are the chief materials of living protoplasm.

Simple sugars can be made only in cells that contain chlorophyll and are exposed to light. Changes from sugar to other foods, and from other foods back to sugar, can be made in any living cell, with or without light. The same changes do not occur in all kinds of plants. Onions, for example, rarely or never form starch.

In the Cells

Foods *made* by plant cells are *used* by plant cells, too—but not before most of them (except the simple sugars) go through further changes. They must be *digested*, changed to substances that are simpler or that are soluble in water. Then they can be used either in the cells where they were made or transported to other cells. Several times I have mentioned that these foods have two important uses: (1) to provide energy for various plant activities; and (2) to serve as materials from which protoplasm, cell walls, and various other substances, such as chlorophyll, are formed. Sometime you may have an opportunity to learn more about this subject.

From Cell to Cell

In most many-celled green plants, foods are moved about through the plant body from cells where they are made to other cells where they may be used or stored. Here is an example. In green leaves, sugar is

Observe Oxygen Bubbles

You will need: (1) a glass jar about 6 inches deep; (2) clear, cool water; (3) about 6 sprigs of *Elodea;* (4) sunshine.

With scissors, cut about 4 inches from the tip of each *Elodea* sprig. Cut between places where leaves are attached. Put the sprigs, tip down, well under water, as shown on page 27. Set the jar in sunlight and watch for bubbles from the cut ends of the stems. Don't be disappointed if *every* sprig doesn't free oxygen as it makes sugar. Often they do not, but at least one should.

When the bubbling is well started, count the number of bubbles per minute as accurately as you can. Then shade your jar. Make another bubble count. Is good light a help?

Prepare two jars of *Elodea* sprigs as nearly alike as you can. Put them both in a warm sunny place. When bubbles have started in both jars, put one in a cold, sunny place—outside the window, for example. Does temperature make a difference?

Try the following when you have two jars of *Elodea,* both producing oxygen bubbles. With a soda straw, blow your breath gently through the water in one jar. Your breath contains carbon dioxide, you know. Does added CO_2 make a difference in the number of bubbles?

And Then What?

Making food by photosynthesis is only one of the interesting processes that go on in living plants. It alone operates only in light and depends on chlorophyll. We hope that this Leaflet has helped you to understand better this marvelous food-making process without which neither plants nor animals could live on this earth.

In the next few paragraphs, you will read a little about some other plant processes. I have written about them separately. But they do not occur separately. Most of them are in operation all the time, day and night. During its growing season, a living plant is a busy factory with many departments on a 24-hour shift. Even in winter, plant activities do not stop entirely in plants that live through that season.

From Sugar to Other Foods

The sugar produced by photosynthesis is a useful food in itself. It is also a "raw material"

Something to Think About

The product of all these plant processes—and some I haven't mentioned—is the plant itself, a living thing, growing like others of its kind, and producing seeds or other means by which new plants of its kind may grow.

Of course, green plants of different kinds do not grow as they do *for* us, nor for other animals nor other plants. But think of all the useful things we get from green plants of different kinds: food, clothing, wood, flavorings, fibers, medicines, and,—; how many more can you add? Think, too, of all the human industries that depend for materials and energy on green plants.

Plants are wonderfully interesting living things. You may not be able to watch them move about, get food, care for their young, and do other things that animals do. But the more one learns about plants and how they grow, the more one recognizes them as active, changing, living things. No wonder that botany—and sometimes only one special part of the science of plant life—is a lifetime study for many scientists. It may be for some of you.

Books to Help You

The books listed on this page are some that I believe will be helpful. You may find others in your library.

Plant Factories. By Bertha M. Parker and Orlin D. Frank. Row, Peterson and Company, Evanston, Illinois. 1950. 36 pages. A well-illustrated, attractive booklet planned for pupils of grades 4, 5, and 6. This is one of a large number of Unitexts in the Basic Science Education Series. Other Unitexts, useful in the studies suggested in this Leaflet, are: *Dependent Plants,* 1944; *Foods,* 1946; *Leaves,* 1949; *Living Things,* 1941; and *The Plant World,* 1949.

Plants in the City. By Herman and Nina Schneider. The John Day Company, New York City. 1951. 96 pages. A book full of things to look for and do.

Play With Plants. By Millicent Selsam. William Morrow and Company, New York City. 1949. 63 pages. A fascinating book about plants and how to grow them, with many experiments.

This Green World. By Rutherford Platt. Dodd, Mead and Company, New York City. 1944. 222 pages. Well-illustrated and

produced by photosynthesis. Often it is changed immediately to starch and stored in the leaf during the day. At night the starch may be changed back to sugar, and the food then moved to some other plant part, where it is used or stored.

The pathway through which *foods* travel is different from the water-conducting system about which you have read (pages 18 to 22). Foods, dissolved in water, travel through *living* cells. Those cells form a "distribution system" that begins in the fine veins of leaves, for example, continues in the larger veins, passes through leaf petioles, down through stems, and finally into the outermost roots. Just as every cell in a leaf is near enough to a water-conducting tube to get water, so every living cell in a plant is near enough to food-conducting cells to get a supply of food. Much of the food goes to roots, to growing tips of stems or branches, and to other plant parts, such as expanding leaves and developing flowers or fruits, where active growth is taking place. Some is stored in various plant parts—you can learn about that in your science books.

Test for Starch in Leaves

You read (above) that sugar in leaves often is changed to starch during the day when photosynthesis is going on rapidly. When iodine is added to starch, it stains the starch blue or purplish. To test a green leaf for starch you need to remove the chlorophyll as suggested on page 15. Wash your leaf in clean water when you take it out of the alcohol. Put it on a piece of clean glass or on a white dish—not on paper, especially white paper, which often contains starch. Then drop iodine (tincture of iodine will do) on it from a medicine dropper. If the leaf contains starch, its color will change to blue or bluish gray.

Test a leaf from a healthy, well-watered plant that has stood for several hours in bright light in your schoolroom. Cover the plant with a cardboard carton or other lightproof cover, and leave it in darkness for 48 hours. Then test another leaf.

Test leaves from more than one kind of plant. Some do not store starch in their leaves.

If you can get a leaf that is partly green and partly white, test it for starch. Take it from a plant that has been in light for several hours. When you have extracted the chlorophyll and washed the leaf, lay it on a white dish. Drop iodine on it. Did the white part and the green part stain equally?

interesting. For older readers.

The Golden Treasury of Natural History. By Bertha M. Parker. Simon and Schuster, New York City. 1952. 216 pages. A beautiful book illustrated in color. Space is divided among the animal kingdom, the plant kingdom, and the sun and stars. Many subjects that are included in the Basic Science Education Unitexts are discussed here, and the book has many helpful, attractive illustrations.

Science textbooks will help answer questions, and will tell more about many of the subjects discussed in this Leaflet. The many pictures in them are attractive and helpful, too. The fourth, fifth, and sixth grade books are perhaps the most useful. You will be fortunate if you have more than one of the following series to work with. Each one usually makes some special contribution. You can compare what one book tells you with the information in another.

Basic Studies in Science: Discovering Our World. Books 1, 2, and 3. By W. L. Beauchamp, Mary M. Williams, and Glenn O. Blough. Scott, Foresman and Company, Chicago, Illinois. 1952.

Exploring Science, Books Four, Five, Six. By Walter A. Thurber. Allyn and Bacon, Boston, Massachusetts. 1955.

Heath Elementary Science: Science in Your Life, Science in Our World, Science for Today and Tomorrow. By Herman and Nina Schneider. D. C. Heath and Company, Boston, Massachusetts. 1955.

Science for Modern Living: Across the Land; Through the Seasons; Beneath the Skies. By V. C. Smith and Barbara Henderson. J. B. Lippincott Company, Philadelphia, Pennsylvania. 1951.

Science Today and Tomorrow: Discovering with Science, Adventuring in Science, Experimenting in Science. By Gerald S. Craig and Co-authors. Ginn and Company, Boston, Massachusetts. 1955.

Singer Science Series: Exploring Together; Doing Experiments; Solving Problems. By G. W. Frasier, Helen D. MacCracken, and D. G. Decker. The L. W. Singer Company, Syracuse, New York. 1955.

Understanding Science: Explaining Why; Discovering Why; Understanding Why. By Thomas I. Dowling and Others. The John C. Winston Company. Philadelphia, Pennsylvania. 1951.

The Wonderworld of Science, Books 4, 5, and 6. By Warren Knox and Others. Charles Scribner's Sons, New York City, 1950.

Published by the New York State College of Agriculture at Cornell University, Ithaca, New York. M. C. Bond, Director of Extension. This leaflet is published and distributed in furtherance of the purposes provided for in the Acts of Congress of May 8 and June 30, 1914.